THE CONFINED HELIUM EXPERIMENT (CHEX): THE SUCCESSFUL RETURN OF THE LOW TEMPERATURE PLATFORM FACILITY (LTPF) TO SPACE

Melora Larson, David Pearson, Steve Elliott, Dusan Petrac, Ulf Israelsson, and Tom Luchik

Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Dr., Pasadena, CA 91109

ABSTRACT

The Low Temperature Platform Facility (LTPF) flew on STS-87 from November 19 to Decemnber 5, 1997 as part of the fourth United States Micrograviry Payload (USMP-4). During this flight, the LTPF contained the Confined Helium eXperiment (CHeX). The CHeX mission was a success because the LTPF functioned as expected, and the LTPF dewar provided a stable, long lived cooling source for the CHeX instrument. The LTPF is a NASA/JPL facility that is designed to accommodate space shuttle based science experiments or instruments that need cryogenic temperatures near 2K. The LTPF had flown two times prior to this most recent flight: in 1984 as the Superfluid Helium Experiment on Space Lab-2 and in 1992 as the Lambda Point Experiment (LPE) on USMP-1. The facility has been substantially upgraded between every flight. For the CHeX mission, the improvements to the facility were driven by the need to meet updated Space Shuttle requirements and by the desire to increase the scientific return from the mission. These improvements involved changes to both the cryostat and the facility electronics. We report on the flight performance of the LTPF during the most recent mission (CHeX) and on some of the lessons learned while preparing for this mission.

1. INTRODUCTION

The Low Temperature Platform Facility launched in late November 1997 containing the Confined Helium eXperiment (CHeX) as part of USMP-4. The CHeX experiment was a follow-on experiment to the Lambda Point Experiment (LPE). Like LPE, CHeX measured the specific heat of liquid helium near the superfluid fluid transition. In contrast to LPE, CHeX studied how the behavior in a finite sized sample differs from the behavior of a bulk sample. The science being studied by CHeX can only be seen in a microgravity environment because earth's gravity smears the region of interest for any ground based experiments.

The LTPF was built to provide a platform for short duration (less than 2 weeks), Space Shuttle based experiments that need temperatures near 2K in a microgravity environment. The LTPF (see Figure 1) consists of a cryostat to cool the experiment and electronics that provide the interface between the experiment and the Space Shuttle.

2. FACILITY OVERVIEW

The main component of the LTPF cryostat is a 100 liter superfluid helium dewar. The LTPF dewar uses a porous plug of sintered metal to contain the liquid helium while in free fall. The bath is cooled while in orbit by allowing the vacuum of space to pump on the helium through the porous plug. Prior to launch, the cooling for the bath is provided by a mechanical vacuum pump in the Vacuum Maintenance Assembly (VMA). The pump in the VMA is shut off about 30 minutes prior to launch. Because the LTPF has been used for experiments that are extremely sensitive to variations in the externally applied magnetic field, the dewar is surrounded by a μ-metal shield that attenuates the external magnetic field by 50dB.

The LTPF electronics consist of three computers, the Cryostat Electronics Assembly (CEA), the Telemetry Control Assembly, and the Experiment Control Assembly (ECA) and two additional boxes for the incoming power. The CEA is dedicated to facility functions. The CEA provides readouts for all housekeeping sensors, and it controls the heaters associated with the facility. The ECA is dedicated to controlling the experiment installed in the LTPF. The TCA provides the interface between the LTPF and the Space Shuttle. The TCA also controls the motor driven vent valves installed on the facility.

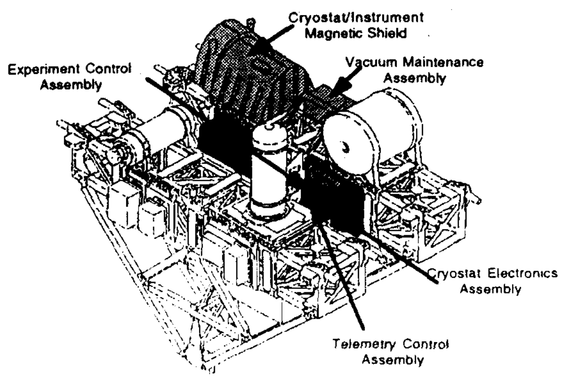

***Figure 1**: USMP-4 and CHeX schematic block diagram.*

3. HISTORY

The LTPF was built in the early 1980's for the Superfluid Helium Experiment (SFHE). The SFHE was designed as a technology demonstration to investigate the behavior of superfluid helium in a microgravity environment. The SFHE flew as part of Spacelab-2 on the Shuttle Challenger in 1985. The SFHE was originally developed to be the first test of containing liquid helium in free fall, but before SFHE flew, the Infrared Astronomical Satellite (IRAS) flew. IRAS proved by its success that superfluid helium could be contained and cooled with out the presence of gravity. Even though SFHE was not the first flight of superfluid helium in space, it was a success because of the extensive housekeeping instrumentation in the dewar. Also, SFHE was able to show that if the helium bath warmed above the superfluid transition temperature, it could be cooled back into the superfluid state in a reasonably short period of time by pumping through the porous plug.[1]

Before the LTPF's second flight in 1992, the facility was upgraded to be able to include an integrated scientific instrument. The primary change made to the LTPF to facilitate the addition of an experiment was the addition of a new computer dedicated to the experiment, the ECA. The ECA was added to the two computers that had flown on SFHE, the CEA and the TCA. Because the first experiment manifested for the LTPF was very sensitive to external magnetic fields, a magnetic shield was also added to the LTPF to surround the dewar. There were also a few other general refurbishments to the cryostat that were necessary after SFHE.

Once these modifications were made to the facility, the Lambda Point Experiment (LPE) was integrated with the LTPF. LPE flew as part of the first United States Microgravity Payload (USMP-1) on the Shuttle Columbia in the fall of 1992.[2] LPE made very precise measurements of the specific heat of a sample of very pure bulk helium-4 near the superfluid transition, or Lambda Point, that were not possible to make on the ground. LPE was able to measure the specific heat with a temperature resolution of about 1nK, to achieve measurements within 2nK of the transition.[3]

The LTPF just returned from its most recent flight as the Confined Helium eXperiment (CHeX) on USMP-4. USMP-4 flew on the Shuttle Columbia, STS-87, in late 1997. The CHeX experiment carried out an extension of the science studied during the LPE. Many improvements were made to the LTPF in preparation for this flight, and these improvements will be discussed in detail in the following section. From the experiences during the CHeX integration and test phases, several lessons were learned about processing cryogenic experiments. These lessons will be discussed in section 5. Finally, the flight results will be discussed in section 6.

4. IMPROVEMENTS

Several changes were made to the LTPF prior to the flight in late 1997. The cryostat was modified to increase the liquid helium lifetime to take advantage of the length of an extended duration shuttle mission. The cryostat also had to be modified in order to meet new, stricter Space Shuttle launch constraints imposed by having the CHeX payload as a Launch Commit constraint. These changes included both physical modifications to the cryostat and procedural changes. When the effects of all the changes are combined, they were expected to give a 15% increase in the helium lifetime over what was achieved for LPE. The facility electronics were also improved for this flight. The electronics improvements included higher resolution readout electronics for the housekeeping sensors as well as the addition of power monitoring and fusing capabilities.

Physically, the cryostat consists of a helium dewar with two vapor cooled shields, three manual room temperature actuated valves that are heat sunk to the helium bath (V3, V4, and V5), and several housekeeping sensors and heaters with wiring connecting these components to room temperature (see Figure 2). The cryostat also has four manual vent valves that are at room temperature (V2, V6, V7, and V8), and five motor driven vent valves that can be operated while on orbit (VV1 through VV5). Finally, the Vacuum Maintenance Assembly (VMA) has 2 solenoid valves (VV6 and VV7) that are activated only while the VMA mechanical pump is operating.

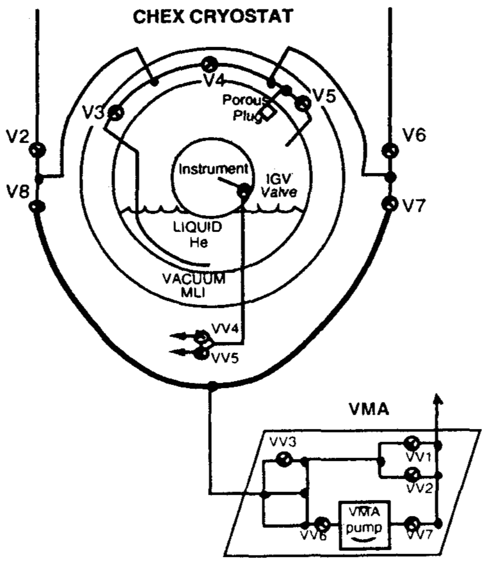

Figure 2: Schematic drawing of the LTPF cryostat in the configuration flown with CHeX. All remotely operated valves are designated as "VV", while the manual valves are designated with a single "V".

Before the LTPF was integrated with the CHeX experiment, a coordinated effort was made to decrease the total amount of heat that reached the cryostat helium bath. [4] First, the connection between the vapor exhaust plumbing and the vapor cooled shields was significantly improved with the addition of multiple copper straps soldered to both the stainless steel vent plumbing and the aluminum shields. Then, all of the copper wiring in the cryostat was replaced with wire of a lower thermal conducting material (manganin). Also, all of the housekeeping wiring was firmly heat sunk to the vent plumbing at both the inner and outer vapor cooled shields. Finally, the guide tubes for the cold valves were modified to decrease their contribution to the bath heat load. All of these changes caused a 10% decrease in the helium boil-off rate when compared to LPE (see Figure 3).

The total lifetime improvement expected between LPE and CHeX was 15%. The remaining 5% improvement in the lifetime was created by modifying the liquid helium fill procedure. For LPE, the dewar was filled prior to launch one time with the temperature of the helium at the end of the fill reaching approximately 2.5K. Once the helium had cooled back to below the superfluid transition, a total of about 79 liters of the more than 90 liters transferred remained in the dewar (see Figure 3). For CHeX, a new "double" top-off procedure was developed. As the name implies, this method involved performing two fills of the LTPF dewar in quick succession. The dewar would be first filled with helium just over 2.3K. Then both the flight dewar and the supply dewar were pumped until the flight dewar has cooled below 1.9K (because of the construction of the supply dewar, the helium in the supply dewar does not drop below 2.2K during the fill procedure). After the flight dewar reached 1.9K, another top-off is performed. By repeating the fill, a total of at least 85 liters of liquid helium remain in the dewar after the helium has cooled to near 1.9K (see Figure 3). The 6 liter increase in the fill level over LPE gives the CHeX dewar and additional 5% improvement in the dewar.

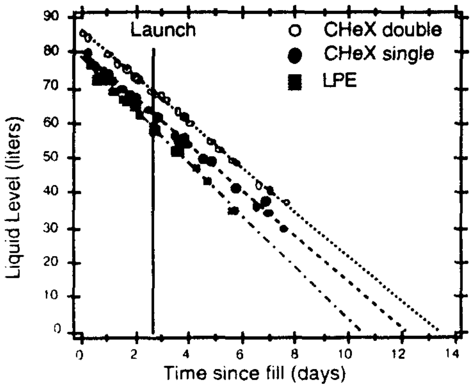

Figure 2: Liquid helium lifetime comparison using ground data of LPE versus CHeX. The vertical line marks the expected time since fill for launch.

This means that while LPE lasted for approximately 9.5 days on orbit after over 2.5 days on the ground, CHeX was expected to last for at least 11 days on orbit.

Another procedural change that was important, but did not affect the total lifetime of the dewar was a change in the method of precooling the plumbing at the start of a liquid helium transfer. For LPE, the precool phase of the transfer, when the fill lines chill to helium temperatures, was accomplished by flowing through the internal bypass plumbing. This caused considerable heating of the experiment instrument. For CHeX, the outer bypass plumbing was insulated with foam so that the precool phase of the transfer could utilize the outer bypass. This method does not impart excessive heat to the instrument. Because it does not heat the instrument, the liquid helium level can drop several liters lower before transfer must occur when compared to LPE. This change does not increase the lifetime of the dewar, but it does increase its useful ground hold time which was necessary to meet the Shuttle's launch scrub turnaround requirements.

5. CHeX FLIGHT

The Space Shuttle Columbia, STS-87, launched in the early afternoon of November 19, 1997. The CHeX experiment was activated 3 hours and 22 minutes after the launch from KSC. When CHeX was activated, it was noticed that the cryostat bath was warmer than had been expected given its temperature just prior to launch and the expected pump down rate. Since the bath external vent valve had opened as expected during the orbiter's ascent, there was no immediately obvious cause for the warmer bath temperature. The most probable cause for the warmer bath temperature is discussed in the lessons learned section below. The bath remained about 0.15K warmer than had been expected prior to the flight for all of the CHeX mission (see figure 4).

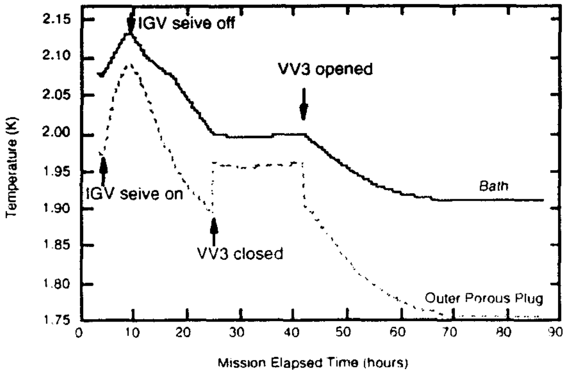

Figure 4: Bath and outer porous plug temperatures during the first three days of the mission. The bath and porous plug temperatures did not change significantly from the final equilibrium values during the remainder of the mission.

During the first two days of the flight, the helium-3 exchange gas installed in the instrument to cool it during launch was removed. This was achieved by first opening the VV4 and VV5 vent valves (see figure 2), and heating the Instrument Guard Vacuum (IGV) sieve for 5 hours (see figure 4). Once the sieve heater was off, the cryostat bath temperature was kept at or above 2.0K for another 35 hours to allow the sieve to pump out all the remnant exchange gas. The bath was kept warm by closing the vent valve VV3 (see figure 4). With VV3 closed, the only vent path for the bath was through an orifice that provided almost 10 Torr of pressure drop. About 40 hours after the IGV evacuation was started, the vent valve VV3 was reopened, and the bath was allowed to cool to its equilibrium value of 1.91K. The bath temperature rose only slightly (less than 10mK) during the remaining 9 days of the mission.

The helium bath was depleted 12 days 2 hours and 38 minutes after launch. The first indication that the helium was running out came when the outer porous plug temperature started to drop, and the inner vapor cooled shield temperature started to rise. The early indications provided about 20 minutes of warning before the CHeX instrument started to warm.

The lifetime achieved by the CHeX flight, 12 days 2.5 hours, was longer than had been predicted using only the measured ground improvements (see figure 3). Because the behavior of any helium dewar is strongly coupled to the outer shell temperature, a numerical spreadsheet model of the CHeX cryostat had been developed to be used during the mission.[4] The model had been shown to correctly predict the cryostat's ground performance for a variety of bath temperatures (1.6K to 4.2K). When the model was used with the actual flight bath heat loads and outer shell temperatures, a predicted lifetime of 12 days and 12 hours after launch was found (see figure 5). This is in good agreement with the actual lifetime because of the uncertainty in the final fill volume.

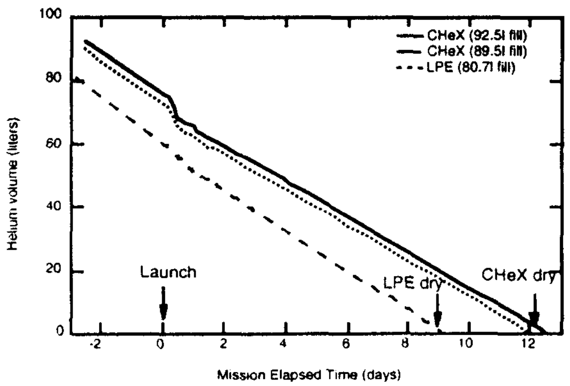

Figure 5: Liquid helium lifetime comparison of the flight data of LPE versus CHeX. The two lines shown for CHeX reflect the uncertainty in the initial fill volume.

6. FROZEN AIR REMOVAL

As mentioned above, the bath was significantly warmer than had been expected prior to launch. While there was no obvious mechanical failure, the history during testing and integration of CHeX provided a likely source for the higher bath temperature. The LTPF had been kept at helium temperatures for 17 months continuously prior to launch. During that time, the dewar was kept below 2K for over 10 months. While the dewar was below 2K, air was ingested into the vent lines due to processing mistakes a total of three times. Each of these plugs was removed by warming the inner vapor cooled shield to above 200K while pumping on the vent line. This technique removed all detectable traces of an impedance in the vent line. This technique was also used successfully to remove constrictions caused by air ingested into capillaries and other small pumping lines.

So, the most likely cause for the warmer bath temperature during the CHeX mission was a constriction formed by the remnant air ingested during processing. While all traces of the constriction could be removed for ground processing, not all of the air ice ingested would be removed. It is likely that during the CHeX mission the remaining air ice was shaken into an inappropriate location during launch. This caused the noticeable impedance of about 6 Torr observed above the expected value during flight. Post flight testing has confirmed that the additional vent line impedance has been removed now that the dewar is at room temperature.

7. CONCLUSIONS

Several significant improvements have been made to LTPF since it last flew in 1992 as LPE. One of the most significant improvements to LTPF since LPE was the increased helium lifetime. The CHeX experiment was able to take advantage of the longer lifetime available to perform science for most of the 15 day Shuttle mission. While the bath temperature during the flight was warmer than expected, the bath temperature was stable, and did not affect the science generated by CHeX. All of the lessons learned from the success of the modifications made to LTPF and from the failures during processing of CHeX will be applied to the new, Space Station based low temperature platform (LTMPF) being developed by JPL in partnership with Ball Aerospace. All of the lessons

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES

1. P. V. Mason, D. Petrac, D. D. Ellimen, T. Wang, H. W. Jackson, D. J. Collins, P. Cowgill, J. R. Gatewood, Adv. Cryo. Eng, **31**, 869, (1986).

2. D. Petrac, U. E. Israelsson, T. S. Luchik, Adv. Cryo. Eng, **39**, 137 (1994).

3. J. A. Lipa, D. R. Swanson, J. A. Nissen, T. C. P. Chui, and U. E. Israelsson, PRL, **76**, 944 (1996).

4. T. S. Luchik, U. E. Israelsson, D. Petrac, S. Elliott, Adv. Cryo. Eng, **41**, 1135 (1996), and to be published.